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Handbooks–Answer Books on Thermal Power Engineering: Problems and Solutions

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Abstract—Problems relating to construction and filling of open interactive network handbooks for specialists in thermal power engineering are discussed. A specific problem of creating "live" calculations using the technology of "cloud calculations" is considered.

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At present, we are witnessing a very rapid growth of technologies using which computation documents created in environments of mathematical computer programs [1–4] can be published on the Internet.[1] Such documents are published not only for reading (this was also done before), but also for carrying out full-valued calculations using them. These documents allow a user to change initial data and obtain an answer in numerical and graphic forms, as well as all intermediate results of computation with presenting the relevant formulas and numerical values of variables used in the formulas.

Such open interactive network computation documents make it possible not only to study different methods of solving particular problems (this can also be done without a computer by opening a usual printed handbook, a book of problems, or an answer book), but also to accomplish a practical purpose, i.e., to carry out calculations and obtain new answers with new initial data.[2]

The most popular mathematical software package for carrying out calculations for engineering and educational purposes is Mathcad [4]. It has become so due to a low threshold of entrance into this software environment, the availability of its version in Russian and extensive literature on this package in Russian, as well as supporting Web sites (e.g., www.mathcad.ru). In addition, computations created in the Mathcad environment contain formulas written in the same form as those given in printed handbooks, books of problems, and answer books, and the spelling of names of variables is fully identical with the spelling that had been established in the relevant scientific disciplines well before the advent of computers. All these factors contribute to the maximal openness of Mathcad computations. It should also be noted that, after minimal adaptation, these calculations can be published ("animated") in a local or global computer network using the Mathcad Application Server (MAS) technology [4].

In recent years, the authors of this paper have published a great number of computation documents in the Internet using the MAS technology, which are related primarily to power engineering (www.vpu.ru/mas). In doing this work, the authors enjoy help from teachers and students of the Moscow Power Engineering Institute (www.mpei.ru) and other educational institutions. For students, such work is an excellent way of studying an educational discipline and gaining skills in creating or carrying out open interactive network calculations. For teachers and researchers this is a good possibility to study modern information technologies and promptly publish the results of their work in the field of calculation of thermal power facilities.

The operation of "animating" books of problems and answer books in accordance with the MAS technology or another similar information technology makes it possible to subject these methodological and reference documents to serious scientific editing and careful proof-reading. In this case, an answer book turns into a very suitable scientific and technical reference document: a combined handbook and answer book.

In addition, the following must be pointed out: application of calculators and computers has resulted in that units of measurement were forced out from calculations. The Mathcad package furnished with tools

[1] This takes place within the framework of a general trend toward development of the technology of so-called "cloud computing," according to which access is provided for users of computers to remote computation resources and disk space ("clouds"), as well as to communication channels. With this technology, there is no need for installing any application computer programs on a user's PC: everything he or she requires can be found on the Internet at a moderate charge or even free of charge.

[2] A book of problems contains descriptions of problems and answers to them, which are usually placed in the end of the book. An answer book contains not only descriptions of problems, but also a detailed description of the problem solution process: a sequence of formulas with concrete numerical values substituted in them.

for operation with not merely numbers, but with physical quantities (length, mass, time, pressure, power, etc.) [1, 4] makes calculations much simpler, performs additional checking of their correctness, and eliminates the problem mentioned above. With the advent of mathematical packages, computers were charged with extra routine work of converting nonbasic units of measurement (hour, millimeter, horsepower, etc.) into basic SI units (second, meter, watt, etc.); it is well known that off-system and even auxiliary units of measurement are often used in scientific literature.

However, the most important aspect pertaining to "animating" methodological documents is the one discussed below. Solution of problems is often reduced to solving systems of algebraic, differential, integral–differential, and other equations. The authors of problems for answer books are often compelled to resort to various assumptions, simplifications, and other "tricks" in order to reduce the solution of problems to a sequential calculation using a set of simple formulas. For example, an exact analytical solution of a system of equations is sought and then given. In more frequent occasions, however, a simplified solution with reservations and assumptions is given. If only a set of ready formulas is proposed to a student instead of giving and analyzing the system of initial equations (a mathematical model), he or she will not be able to fully understand the essence of a problem and methods of its solution. Mathematical packages furnished with powerful numerical and analytical (symbolic) tools for solving systems of equations make it possible to formulate a problem in a new way, paying most attention to its statement in the form of a system of equations (construction of a mathematical model) rather than to concrete methods of its solution.

As an example, we can consider the problem of calculating the thermal efficiency (η_t) of an ideal gas turbine unit (GTU) operating in accordance with the Brayton thermodynamic cycle [5]. The formula for calculating this value can be found in all reference books and handbooks:

$$\eta_t = 1 - \frac{1}{\pi^{\frac{k-1}{k}}},$$

where π is the GTU compressor's compression ratio (the ratio of the pressure at the compressor outlet to that at its inlet), and k is the adiabatic exponent of the cycle's working medium (the ratio of specific heat at constant pressure to that at constant volume).

In describing the problem of determining the thermal efficiency of an ideal GTU, all reference books on thermodynamics give its solution in the simplest way: the values of k and π are specified, and the sought value of η_t is calculated from this (simplified) formula. As a rule, no explanation is given as to how this formula was obtained, nor is it explained what has to be done for taking into account the dependence of the adiabatic exponent k on the temperature and pressure of working medium, how a nonideal nature of the processes through which a working medium is compressed in the compressor and expands (useful work) in the gas turbine can be taken into account, etc. Figure 1 shows another, open, approach for solving this problem.

The list of initial data used to calculate the efficiency of a GTU (Fig. 1) includes the pressure of working medium at the compressor inlet $P1$, the compressor's compression ratio π, the temperature of working medium at the compressor inlet $T1$ and at the gas turbine inlet $T3$, and the values of working medium's specific heat at constant pressure Cp and at constant volume Cv (for ideal air, $Cp = \frac{7}{2}R$ and $Cv = \frac{5}{2}R$, where R is the universal gas constant).

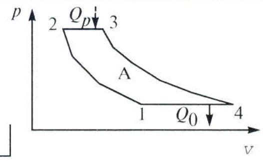
For finding the thermal efficiency of a GTU, the values of working medium's specific enthalpy H at all four points of the cycle are calculated by finding a definite integral of Cp over the temperature. A definite integral is also used in calculating the values of specific entropy S at all points of the cycle. Of course, the integrals appearing in the calculation shown in Fig. 1 can be eliminated taking into account that the variable Cp is a constant and can be withdrawn from under the integral symbol. But real GTUs use real working medium the specific heat of which depends on temperature. The approach for solving the problem of a GTU efficiency shown in Fig. 1 makes it possible to take such dependence, i.e., $Cp = f(T)$, into account. In addition, it is also possible to take into account another "nonideality," which consists in that the entropy of working medium increases as it is compressed in the compressor (i.e., $S2$ is not equal to $S1$, but $S2 > S1$) and expands in the gas turbine ($S4$ is not equal to $S3$, but $S4 > S3$). Also, it is not difficult to take into account pressure losses in the combustion chamber ($P3 \neq P2$) or in the atmosphere ($P4 \neq P1$). The formula given above is a "closed" one, from which nothing can be gained either for education or for the industry. On the contrary, the calculation shown in Fig. 1 is open for both studying purposes and for tying it to real GTU circuits.

The Web site http://twt.mpei.ac.ru/TTHB/2/tdc.html contains open interactive computations for real thermodynamic cycles used in the power engineering of Russia and around the world.

Special attention should be given to the calculations of the thermodynamic cycle at points *2* and *4* (see Fig. 1), the values of temperature at which are determined not from ready formulas but in the course of solving an integral equation by means of the Given–Find block of the Mathcad package.

The MAS technology enables students to carry out calculations not only using ready formulas by varying initial data, but also to enter the required dependences into calculation by themselves. It is important to note that such dependences can be selected either from a http://twt.mpei.ac.ru/MCS/Worksheets/PTU/brayton-cycle-2.xmcd

Brayton cycle – efficiency calculations using basic concepts



$P1/\text{atm} := 1$ $\quad \pi := 5$ $\quad T1/K := 300$ $\quad T3/K := 1200$

$R := 8.314472 \frac{J}{mol\ K}$ $\quad Cp/R := 7/2$ $\quad Cv/R := 5/2$ $\quad$ Recalculate

Point 1

$V1 := \frac{RT1}{P1} = 24.617 \frac{L}{mol}$ $\quad S1 := \int_{T0}^{T1} \frac{Cp}{T} dT - R\int_{P0}^{P1} \frac{1}{P} dP = 70.1505 \frac{J}{mol\ K}$ $\quad H1 := \int_{T0}^{T1} Cp\, dT = 8701.09 \frac{J}{mol}$

Point 2 $\quad P2 := \pi P1 = 5\ \text{atm}$ $\quad S2 := S1$ Line 1–2 is an isoentropic curve

$T2 := T1$ First approximation

Given $S2 = \int_{T0}^{T2} \frac{Cp}{T} dT - R\int_{P0}^{P2} \frac{1}{P} dP$ $\quad T2 := \text{Find}(T2) = 475.14\ K$ $\quad H2 := \int_{T0}^{T2} Cp\, dT = 13797.91 \frac{J}{mol}$

Point 3 $\quad P3 := P2$ $\quad$ Line 2–3 is an isobaric curve

$V3 := \frac{RT3}{P3} = 19.694 \frac{L}{mol}$ $\quad S3 := \int_{T0}^{T3} \frac{Cp}{T} dT - R\int_{P0}^{P3} \frac{1}{P} dP = 97.111 \frac{J}{mol\ K}$ $\quad H3 := \int_{T0}^{T3} Cp\, dT = 34891.88 \frac{J}{mol}$

Point 4 $\quad P4 := P1$ Line 1–4 is an isobaric curve $\quad S4 := S3$ Line 1–4 is an isoentropic curve

$T4 = T2$ $\quad$ First approximation

Given $S4 = \int_{T0}^{T4} \frac{Cp}{T} dT - R\int_{P0}^{P4} \frac{1}{P} dP$ $\quad T4 := \text{Find}(T4) = 757.67\ K$ $\quad H4 := \int_{T0}^{T4} Cp\, dT = 22019.46 \frac{J}{mol}$

$Q_p := H3 - H2 = 21093.771 \frac{J}{mol}$ $\quad Q_0 := H4 - H1 = 13318.364 \frac{J}{mole}$ $\quad \eta_t := \frac{Q_p - Q_0}{Q_p} = 36.881\%$

The answer with the use of simplified formula: where k is an adiabatic exponent and π is a compression ratio.

$k := \frac{Cp}{Cv} = 1.4$ $\quad \eta_t := 1 - \frac{1}{\pi^{\frac{k-1}{k}}} = 36.861\%$

Fig. 1. Open interactive network calculation of the GTU efficiency.

proposed list (which is commonly used), or a user himself or herself can enter the required dependence in a calculation. Figure 2 shows an example of such work: calculating the thermal efficiency of the Otto thermodynamic cycle in the course of an interactive examination.

A student who takes the examination must open the page shown in Fig. 2 in the Internet and enter formulas into the text windows using which the sought quantities at points *1*, *2*, *3*, and *4* of the Otto cycle are calculated. If the equations are composed and entered correctly (it is precisely this that is shown in Fig. 2; immediately after opening this page the text windows were empty), the final answer found from the open algorithm of calculating the thermodynamic cycle returned by the computer after pressing the key "Recalculate" should be the same as that obtained from the simplified formula. In the given Internet-test on thermodynamics, students who are requested to calculate the parameters of the Otto cycle at points *2* and *4*, have to now compose and solve not a single integral equation (see Fig. 1 with the calculation of a GTU), but a system of integral and algebraic equations: Mendeleev–Clapeyron's equation and an equation the right-hand side of which is a definite integral (int) from which the entropy of working medium at a concrete point is calculated.

The authors of this paper, working together with their students (one of them is the third author) undertook the work of converting some books of problems and answer books (related primarily to the field of power engineering) into an open interactive network format. A great number of misprints and errors is revealed in the course of such work, which include not only classical ones, but also such as incompleteness of information (for example, explanation for some variables and constants written in a formula is lacking). If such situations are encountered in mathematical packages, they either interrupt the calculation by error messages or produce an answer different from that given in books.

Various kinds of normative documents [e.g., the Construction Code and Regulations (in Russian, SNiP)], which contain many formulas, and which can and must be "animated" in the Internet, can be related to a special type of answer books. Thus, the SNiP on calculating the thickness of heat network thermal insulation, which is an example of such "animated" normative documents, can be found on http://twt.mpei.ac.ru/MCS/Worksheets/Thermal/Izol-Trub-Teploset.xmcd. The use of insulahttp://twtmas.mpei.ac.ru/mas/Worksheets/Therm/otto_ideal_cycle_test.mcd

$P1/\text{MPa} := 0.1$ $r := 5$ $T1\,[°\text{C}] := 15$ $T3\,[°\text{C}] := 1100$

$R := 8.314472 \frac{\text{J}}{\text{mol K}}$ $Cp/R := 7/2$ $Cv/R := 5/2$

Input formulas and calculate the efficiency of Otto's cycle

Point 1 $T1 = 288.15$ K $P1 = 0.1$ MPa

$V1 := R \cdot T1/P1$ $S1 := \text{int}(Cp/T.\,T = T0...T1) - R\,\text{int}(1/P.\,P = P0...P1)$ $U1 := \text{int}(Cv,\,T = T0...T1)$

$V1 = 23.958115$ L/mol $S1 = 69.087$ J/(K mol) $U1 = 5.969$ kJ/mol

Point 2 $V2 := V1/r$ $S2 := S1$ Line 1–2 is an isoentropic curve

Given $P2 \cdot V2 = R \cdot T2$

$S2 = \text{int}(Cp/T.\,T = T0...T2) - R\,\text{int}(1/P.\,P = P0...P2)$

$\begin{pmatrix} P2 \\ T2 \end{pmatrix} := \text{Find}(P2, T2)$ $P2 = 0.952$ MPa $T2 = 275.39°\text{C}$ $U2 := \text{int}(Cv,\,T = T0...T2)$

$U2 = 11.381$ kJ/mol

Point 3 $V3 := V2$ Line 2–3 is an isochoric curve $P3 := R \cdot T3/V3$

$S3 := \text{int}(Cp/T.\,T = T0...T3) - R\,\text{int}(1/P.\,P = P0...P3)$ $U3 := \text{int}(Cv,\,T = T0...T3)$

$V3 = 4.79163$ L/mol $S3 = 88.161$ J/(Kmol) $U3 = 28.522$ kJ/mol

Point 4 $V2 := V1$ Line 1–4 is an isochoric curve $S4 := S3$ Line 3–4 is an isoentropic curve

Given $P4 \cdot V4 = R \cdot T4$

$S4 = \text{int}(Cp/T.\,T = T0...T4) - R\,\text{int}(1/P.\,P = P0...P4)$

$\begin{pmatrix} P4 \\ T4 \end{pmatrix} := \text{Find}(P4, T4)$ $P4 = 0.25$ MPa $T4 = 721.32$ K $U4 := \text{int}(Cv,\,T = T0...T4)$

$U4 = 14.973$ kJ/mol

$q1 := U3 \cdot U2$ $q2 := U4 \cdot U1$ $\eta_t := (q1 \cdot q2)q1$

Recalculate

Answer based on simplified formula: $1 - \frac{1}{r^{\left(\frac{C_p}{C_v} - 1\right)}} = 47.47\%$

Your answer $\eta_t = 47.47\%$

Fig. 2. Network interactive examination on thermodynamics.

tion having insufficient thickness results in inadmissible heat losses, while the use of insulation having excessive thickness results in overconsumption of insulating material. This typical technical–economical problem (minimizing the total cost of designing, construction, operation, and subsequent abolishing of an industrial facility after its functions have been fully accomplished) can be solved each time individually, or it is possible to use generalized SNiPs, which will eventually result in a smaller cost of designing.

Touching the topic of normative documents, we cannot but mention the problem of certifying calculation procedures. The validity of information contained in printed handbooks is confirmed to certain extent by high reputation of the appropriate publishing houses with their staff of scientific consultants, editors, and proof-readers. As it regards Web-sites, they are usually handed over to casual makers, and they do not undergo strict editing and careful proof-reading. At the same time, even handbooks issued by very reputable publishing houses contain quite a number of misprints.

There are two methods using which normative documents published in the Internet can be certified. First, a letter from a competent organization confirming the correctness of calculations can be placed on the Internet. And, second, references to the relevant computation sites can be made from the websites of such organizations, and mention can be made about this on the computation site itself.

Given below is a list of handbooks–answer books that are available on the Internet on the site of the Moscow Power Engineering Institute (Technical University) for interactive use:

—on higher mathematics, http://twt.mpei.ac.ru/math;

—on physical quantities, http://twt.mpei.ac.ru/pvhb;

—on thermal engineering and thermal power engineering, http://twt.mpei.ac.ru/tthb.html;

—on the principles of hydraulics, thermal engineering, and aerodynamics, http://twt.mpei.ac.ru/GDHB/OGTA.html;

—on the thermophysical properties of working media used in power engineering, http://twt.mpei.ac.ru/ochkov/WSPHB/index.html;

—on thermodynamic cycles, http://twt.mpei.ac.ru/TTHB/2/tdc.html;

—on hydraulic and gas dynamics, http://twt.mpei.ac.ru/gdhb;

—on pipelines used at thermal power stations, http://twtmas.mpei.ac.ru/mas/Worksheets/HBPipePP/pipes.html;

—on chemical kinetics, http://twtmas.mpei.ac.ru/mas/Worksheets/Chem/ChimKin.html;

—on chemical thermodynamics, http://twt.mpei.ac.ru/TTHB/1/HBThermValues.html;

—on electrical safety, http://twt.mpei.ac.ru/TTHB/EB;

—on heat and mass transfer, http://twt.mpei.ac.ru/ochkov/Diff_MC/web_HMT/index_HMT_E-Book.htm;

—on ion exchange resins, http://twt.mpei.ac.ru/TTHB/1/Dow;

—on automatic control theory, http://twtmas.mpei.ac.ru/mas/Worksheets/Rotach; and

—on reducing noise produced by power-generating equipment, http://twt.mpei.ac.ru/TTHB/1/Tupov.html, etc.

Thus, "animation" of handbooks, books of problems, and answer books on the Internet makes it possible:

(i) to revise how to correct the problems placed in printed handbooks and books of problems are stated and solved,

(ii) to place practice-oriented problems on the Internet, and

(iii) to organize check of students' knowledge by asking them to solve problems not by computations but directly through entering formulas.

REFERENCES[3]

1. V. F. Ochkov, *Physical and Economic Quantities in Mathcad and Maple (Ser. Dialog with a Computer)* (Finansy i Statistika, Moscow, 2002) [in Russian].
2. V. F. Ochkov and G. G. Yan'kov, "A Handbook and Website Complex and the Knowledge Communication Problem," Trudy Akademenergo, No. 1, 35–43 (2009).
3. V. F. Ochkov, "MA and MAS: Problems and Solutions Related to Creation of Web Resources for the Sphere of Education," Vopr. Internet Obrazovaniya, No. 29, 29–32 (2005).
4. V. F. Ochkov, *Mathcad 14 for Students and Engineers: the Official Russian Version* (BHV-Petersburg, St. Petersburg, 2009) [in Russian].
5. V. F. Ochkov, A. A. Aleksandrov, V. A. Voloshchuk, et al., "Calculations of Thermodynamic Cycles via Internet," Teploenergetika, No. 1, 77–80 (2009) [Therm. Eng., No. 1 (2009)].

[3] Literature in which V.F. Ochkov is one of the authors is available on the site http://twt.mpei.ru/ochkov/work2.htm. An extended version of this paper with all operating Internet links can also be found on this site.